

# CONNECTICUT RIVER AMERICAN SHAD MANAGEMENT PLAN



**Connecticut River Atlantic Salmon Commission**  
**103 East Plumtree Road**  
**Sunderland, Massachusetts 01375**  
*Approved June 9, 2017*

## INTRODUCTION

The Connecticut River population of American Shad has been cooperatively managed by the basin state and federal fishery agencies since 1967. In that year the “Policy Committee for Fishery Management of the Connecticut River Basin” was formed in response to the passage of the 1965 Anadromous Fish Conservation Act (Public Law 89-304) by the U.S. Congress. This committee was replaced by the more formal “Connecticut River Atlantic Salmon Commission” (CRASC), which was created by act of Congress (P.L. 98-138) in 1983 (Gephard and McMenemy 2004) and coordinates restoration and management activities with American Shad (<http://www.fws.gov/r5csc/>). The CRASC American Shad Management Plan had a stated objective of 1.5 to 2.0 million fish entering the river mouth annually (CRASC 1992). Diverse legislative authorities for the basin state and federal fish and wildlife agencies, including formal agreements to restore and manage American Shad, have been approved over time and are listed in Appendix A. The following Plan updates the existing CRASC Management Plan for American Shad in the Connecticut River Basin (1992), in order to reflect current restoration and management priorities and new information. An overview of American Shad life history and biology is provided in Appendix B.

Annual estimates of adult returns to the river mouth for the period 1966-2015 have ranged from 226,000 to 1,628,000, with an annual mean of 638,504 fish (Appendix C). Access to historical habitat has increased since 1955 when the first modern-era fishlift was constructed at Holyoke Dam, with significant passage improvements made when the fishlift was rebuilt in 1976 and again in 2004. Since 1980, access to additional habitat has increased through the deterioration of the Enfield Dam and fishway construction at three main stem and four tributary dams. Bellows Falls, Vermont (river kilometer-rkm 280) has been identified as the historic extent of the species’ range on the main stem river, but a fishway completed in 1984 to pass Atlantic Salmon upstream at that barrier now allows shad to migrate beyond that dam (Figure 1; Appendix D and E).

The size of the annual shad run increased from 1967 to 1992 concurrent with the installation of fishways at main stem dams but the population experienced a dramatic and unexpected decline beginning after 1992 (Crecco and Savoy 2004). Some recovery has occurred from 2012-2016 as the number of shad lifted at Holyoke has exceeded the mean annual count for the period 1976-2011, in each of these recent years (Appendix E). At this time, the Connecticut River American Shad population is considered stable, but at reduced levels of abundance, according to the Atlantic States Marine Fisheries Commission’s (ASMFC) American Shad Benchmark Stock Assessment (ASMFC 2007).

In the Connecticut River, fishway passage counts (Appendix E) are an important metric to help determine adult abundance and trends over time, although many factors can influence fish passage rates and counts within and among years. Additional long-term population monitoring information includes stock structure data (e.g., age, spawning history) for Holyoke Fish Lift and downstream areas, as well as a juvenile shad seine survey, conducted by the Connecticut Department of Energy and Environment (CTDEEP) (Appendix F and G). Other long-term monitoring data compiled by the CTDEEP include landings and effort data for the lower river commercial gill net fishery (Appendix G).

Beginning in 2013, commercial (in-river only) and/or recreational harvest of American Shad by a state required a Sustainable Fishery Management Plan approved by the Atlantic States Marine Fisheries Commission (Amendment 3 to the ASMFC Interstate Fishery Management Plan for Shad and River Herring, 2010). Subsequently, the State of Connecticut developed an ASMFC approved Sustainable Fishery Management Plan (2012) that maintained both its commercial and recreational fisheries, with harvest. Massachusetts also received approval to maintain a recreational fishery with allowed harvest (MADMF 2012). The State of New Hampshire chose not to develop a sustainability plan and therefore its fisheries are limited to catch-and-release. Vermont is not a member of ASMFC and is free to maintain a recreational fishery without a sustainability plan but has followed New Hampshire’s regulations. In

addition, ASMFC required development of a Habitat Plan for American Shad, which was completed by both the State of Connecticut for its portion of the basin and CRASC for the entire basin. Both were approved in 2014 (ASMFC 2014).

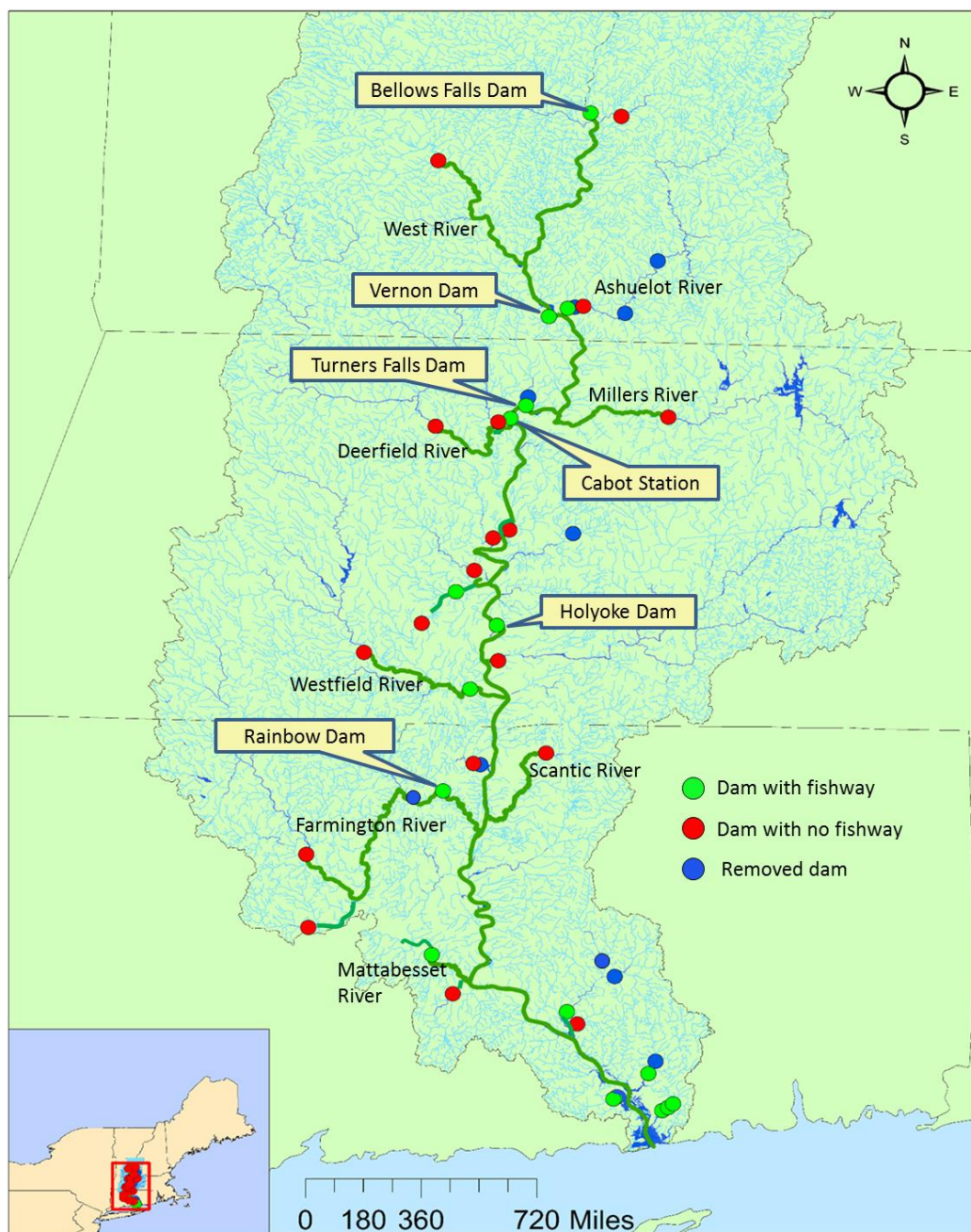


Figure 1. Restored habitat access within the historical range of American Shad in the Connecticut River.

American Shad have also been designated as a “Species of Greatest Conservation Need,” as stated in the comprehensive State Wildlife Action Plan(s), in each of the four basin states (TWW 2015). This designation recognizes the need to develop and implement conservation strategies and actions to improve American Shad’s status in the Connecticut River basin.

This Plan reflects knowledge gained since the development of the 1992 American Shad Plan, which includes advances on shad population status and dynamics, physiology and energetics, reproduction, movement/behavior, fishway use/passage, fishway design/modification, and both fishway and facility operation and flow management.

## GOALS

*To restore and maintain a naturally reproducing American Shad population to its historic range in the Connecticut River basin at targeted management levels of both abundance and stock structure, to provide and maintain recreational fisheries in the four basin states and the traditional in-river commercial fisheries for the species in Connecticut, and provide for the diverse ecological benefits derived from all life stages of shad in freshwater, estuarine and marine habitats.*

## OBJECTIVES

### 1. POPULATION

- 1.1 Achieve and sustain a minimum population of **1.7** million adult American Shad entering the mouth of the Connecticut River annually based on **8,800 hectares** (ha) of spawning and nursery habitat in the main stem and identified tributaries (Appendix I); and
- 1.2 Achieve and sustain a management target adult return rate of a minimum of **203 adults per hectare in the main stem** (Appendix I); and
  - 1.2.1 Achieve a run of > 1,027,000 shad downstream of Holyoke;
  - 1.2.2 Pass > 687,000 shad at Holyoke Dam; and
  - 1.2.3 Pass >397,000 shad at Turners Falls Dam; and
  - 1.2.4 Pass >227,000 shad at Vernon Dam; and
- 1.3 Achieve and sustain a management target adult return rate of a minimum of **111 adults per hectare in targeted tributaries** (Appendix I); and
- 1.4 Achieve an adult stock structure that over a five-year running average has a repeat spawner component minimum of **15%** for each sex; maintains a sex ratio close to 1:1, and is composed of a diverse age structure, including fish age-6 and older; and
- 1.5 Establish safe, timely, and effective upstream and downstream fish passage for returning adults, post spawn adults, and juveniles; and
- 1.6 Establish upstream passage performance measures, addressing fishway attraction, entry, internal passage efficiency and delay at these three stages, as suitable information is available, to support other objectives of this Plan; and
- 1.7 Establish downstream performance measures, for adult and juvenile life stages that maximizes survival for through-project passage and that address downstream bypass route attraction, entry, passage efficiency, and delay, as suitable information is available to support objectives of this Plan.

### 2. FISHERIES

- 2.1 Maintain and/or establish a sustainable spring shad recreational fishery with harvest opportunities throughout its historical range on the main stem and on targeted tributaries guided by population size and fish passage objectives from this Plan; and
- 2.2 Enhance and promote recreational fishing opportunities throughout the species' historical range; and
- 2.3 Maintain a sustainable spring in-river commercial fishery in the lower main stem river in Connecticut; and
- 2.4 Participate in other fisheries management organizations to support science-based management of Connecticut River American Shad fisheries.

### **3. ECOLOGICAL**

- 3.1 Maintain an American Shad population to provide the diverse ecological contributions of American Shad, at all life stages, in the freshwater, estuarine, and marine environments, based upon population targets listed under 1.2 and 1.3.

### **4. MONITORING AND RESEARCH**

- 4.1 Conduct fishery independent and dependent monitoring programs to assess population status and trends; and
- 4.2 Periodically determine long and short-term research needs to achieve or evaluate the Plan Goal and Objectives; and
- 4.3 Identify anthropogenic impacts that limit achieving the other Objectives of this Plan and develop corrective measures.

### **5. PUBLIC OUTREACH AND EDUCATION**

- 5.1 Provide communications and education for the public on the CRASC Plan, and the benefits and ecological values of American Shad in the Connecticut River, Long Island Sound, and the East Coast in the Atlantic Ocean.

## **STRATEGIES**

### **1. POPULATION**

- 1.1 Increase American Shad access to spawning and nursery habitat in both the main stem and the targeted tributaries when possible; and
- 1.2 Determine if fish passage measures are safe, timely, and effective for upstream migrating adult and downstream migrating adults and juveniles, at individual dams, hydropower projects, for cumulative project effects, and assess whether Plan Goals and Objectives are being achieved. Develop corrective action plans as needed; and
- 1.3 Monitor hydropower operations and facilities for any detrimental effects that may impact Plan Goals and Objectives. Develop corrective action plans as needed; and
- 1.4 Conduct annual pre-season, in-season, and post season inspections of fishways, by qualified fish passage specialists (biologist and engineers), to ensure they are functioning within design criteria; and
- 1.5 Evaluate annually information for stock status, trends of metrics and special study results to determine if adaptive management approaches should be developed.

#### **Supporting Narrative**

The adult American Shad production target(s), which are based on accessible and potentially accessible spawning and nursery habitat area and future mixed age class spawning stock returns (within year), have been utilized in other recent American Shad plans and studies including the Roanoke River, Virginia (Harris and Hightower 2015); Susquehanna River, Maryland, Pennsylvania, New York (SRAFR 2010); Merrimack River, Massachusetts, New Hampshire (USFWS 2010); and Penobscot River, Maine (MDMR 2008). The CRASC Management Plan for River Herring in the Connecticut River Basin (2004) provides river surface areas in hectares (ha) for the main stem to determine habitat estimates for this Plan. CRASC biologists reduced the estimated available habitat from the River Herring Plan by 15% (or 852 ha) to account for the brackish water habitat in the lower Connecticut River, which is unsuitable spawning and nursery habitat for American Shad.

This Plan has a minimum target annual adult return/production rate of 203 adults/ha for the main stem, derived from Connecticut River specific estimates for adult returns and composed of multiple age

classes of both sexes to the river mouth in relation to available habitat. The highest estimated adult shad return to the river mouth (1992), when divided by the number of hectares of all available main stem habitat to Bellows Falls, Vermont yields a return/production of 203 adults/ha (Appendices E and I). This estimate likely underestimates the full return/production potential due to problems of reduced passage issues (up and downstream) that were known to exist at each dam. CRASC may increase the minimum adult production target values as improvements to habitat quantity and quality and fish passage occur in the future with pending hydropower relicensing opportunities and other advances in technologies and regulatory or partnering opportunities.

The adult return/production rate in identified tributaries was adjusted to 55% (111 adults/ha) of the main stem production and is consistent with tributary adult shad targets identified by each State agency. Research in the Delaware River supports the hypothesis that American Shad home to tributary spawning grounds (Hendricks et al. 2002) so we expect that the abundance of adults entering the Westfield and other rivers are largely independent of abundance trends in the main stem population. Adult production potential from tributaries can be inferred from shad passage counts at the West Springfield Fishway on the Westfield River, Massachusetts operating since 1996, that had a record high passage of 10,300 (2012) into an estimated 92 ha of habitat, yielding an estimate of 111 adults/ha.

Resilience based approaches to population management through actions that protect and promote diverse age structure, life histories, and habitat use will support Population, Fishery, and Ecological objectives identified in this Plan. A population maintained among many river segments and tributaries may have greater reproductive potential to buffer against negative impacts from environmental perturbations over space and time (Hillborn et al. 2003, Schindler et al. 2010). Likewise, diverse age structure and behavioral patterns within a population of migratory fish can help mitigate against stochastic or anthropomorphic effects and capitalize on ideal conditions for population recruitment (Kerr et al. 2010, Secor 2007).

The Connecticut River American Shad population is iteroparous, which has important implications for both population resilience and reproductive potential, as fish fecundity increases exponentially with fish size (Leggett and Carscaden 1978). The proportion of the annual spawning run determined to be repeat spawners has declined over time from a rate of 49% in the late 1950s, (Walburg and Nichols 1967; Limburg et al. 2003), to a mean of 5% for the period 2006-2015 (Appendix G). Factors leading to the decline of repeat spawners during recent decades are not fully understood. There are no historic data on the composition of repeat spawners prior to the presence of main stem barriers and therefore it is difficult to conclude the full impact of dams on the percentage of repeat spawners in the population. It is likely that the historic shad population was comprised of a more diverse age structure and a greater proportion of repeat spawners. However, observations and newly emerging study data have shown that post-spawn shad may not successfully pass downstream of dams, may be significantly delayed at dams, or may use turbines as a primary passage route. The population impact of these scenarios requires further study both at individual hydropower projects and all hydropower projects collectively (cumulative effects). Agency biologists remain focused on addressing any identified increased fish mortality associated with passing within, through or around dams, canals and hydroelectric stations and facilities (e.g., pumped storage facility). Other factors believed to influence the post-spawning survival include bioenergetic demands of migration, delays in migration, duration of migration, water temperature, and distance traveled (Castro-Santos and Letcher 2010). CRASC anticipates improved survival rates of post-spawn shad because of new structural and operational downstream passage

measures at Holyoke Dam (2016), and supports future opportunities including hydropower relicensings, partnering or other mechanisms for passage improvements that address migratory delay and other associated project-attributed sources of increased mortality.

Achieving a minimum repeat spawner proportion of at least 15% for each sex as determined by season average from daily samples at Holyoke Fish Lift will help achieve the Plan Goal and Objectives. The mean percentage of repeat spawners for the period 1990-2000 was only slightly greater at 16%. The 15% minimum value in the Plan represents an approximate three-fold increase from the 2006-2015 mean (Appendix F). Addressing in-river sources of mortality that contribute to decreases in the ability of post-spawn adults to successfully migrate back to the ocean are a focus area for management improvements and has been an area of limited available information. In order to address these information gaps, main stem power companies as part of the FERC relicensing process, have recently completed several studies (in review process) which may be used adaptively for this Plan.

The CTDEEP's age structure analysis demonstrates a reduction of the age-6 cohort (males) and loss of older cohorts (both sexes) over recent decades (ASMFC 2007). This Plan seeks to increase representation of these older cohorts to provide reproductive and stock stability resilience in the event of unfavorable environmental conditions.

## **2. FISHERIES**

- 2.1 Improve all aspects of adult shad passage at fishways and adult abundance in the upper basin to support recreational and commercial fisheries, as determined appropriate by the respective State agency and ASMFC; and
- 2.2 Provide access for shore and boat fishing anglers on the main stem and tributaries; develop information and outreach materials to promote these fishery opportunities as appropriate; and
- 2.3 Help ensure monitoring/data requirements for the ASMFC are obtained in a timely and cooperative manner to prevent fisheries closures; and
- 2.4 CRASC Commissioners and the Technical Committee members should maintain their active participation on the ASMFC American Shad and River Herring Management Board, the ASMFC's Technical Committee for those species in state jurisdictional waters. The New England and Mid-Atlantic Fishery Management Councils' activities should also be monitored as federal marine water management decisions could affect Connecticut River American Shad; and
- 2.5 Support the prohibition on mixed stock fisheries of American Shad.

### **Supporting Narrative**

Fish passage at dams was a focus area for the joint state and federal Cooperative Fishery Restoration Program for the Connecticut River basin (1967), to address the restoration and expansion of fisheries. Significant progress on upstream passage came from the agencies' coordinated efforts that later evolved with the CRASC's formation. Under CRASC, measures to address downstream passage and steps to improve upon initial fishway designs and operations resulted in the expansion of shad fisheries into New Hampshire and Vermont (Appendix C). Fish passage technologies and research tools have advanced over time and continue to evolve with improving science and engineering, including evaluation of fish behavior and physiology. The Federal Energy Regulatory Commission's relicensing process at Turners Falls, Northfield Mountain Pump Storage Facility, Vernon Dam, and Bellows Falls projects offers opportunities to address identified issues that may negatively impact adult shad in and around projects and their fishways, and subsequently improve fisheries in upstream habitat. The use of new information

on shad behavior, physiology, energetics in and around fishways, and related facility operations should be used to update passage measures and management objectives.

According to the ASMFC Interstate Fishery Management Plan for American Shad Management Amendment 3 (2010) a sustainable fishery must “*demonstrate their stock could support a commercial and/or recreational fishery that will not diminish the future stock reproduction and recruitment.*” Only the State of Connecticut and Massachusetts developed and submitted approved Sustainable Fishery Plans for the Connecticut River. The CRASC seeks to achieve a shad population with metrics of abundance and stock structure that will support the development of a Sustainable Fishery Plan as required by the ASMFC for the State of New Hampshire and inclusive of the State of Vermont, allowing recreational harvest. Adult shad passage counts to the habitat upstream of the Turners Falls and Vernon fishways have been variable over the long-term, but in the most recent five years consistent improvement has been demonstrated in the proportion of shad passing Vernon relative to Turners Falls Gatehouse Ladder (Appendix D). However, the agencies will need to document adult passage increases and other population metric objectives before considering the development of criteria for a Sustainable Fishery Plan for the upper basin (New Hampshire and Vermont). Defined target values for passage and other metrics in this Plan will serve as a measure of progress toward achieving the Plan Goal and Objectives.

Recreational fisheries in tributaries may require additional specific considerations. Ultimately, CRASC intends to have recreational fisheries with harvest in all Plan identified tributaries, consistent with Plan Goal and Objectives. The development of recreational fisheries in all basin states and their identified tributaries has the potential to provide extensive recreational opportunities.

American Shad recreational creel survey data had been annually collected for shad by CTDEEP for decades and are provided in reports to ASMFC and other agency publications. Estimated recreational catches for the lower river reached as high as 102,000 fish in 1992, which coincides with the highest estimated run size of 1.63 million fish to the mouth, and the Holyoke Fish Lift passage record of 720,000 shad (CTDEEP 2010). However, studies of recreational fisheries require considerable resources and have become a less common activity since 2000.

Commercial landings data for American Shad in the State of Connecticut began in 1887 with a maximum value of 519,862 kg in 1946 (Appendix G). Currently the only commercial harvest in the basin is a drift gill net fishery in the lower 48 km (30 miles) of the main stem river. In recent decades a decline in in-river commercial fishing effort and landings have been reported by CTDEEP that has been attributed to an aging group of netters with no new license entries (CTDEEP 2012).

The CRASC should continue to work cooperatively with the ASMFC in support of agency efforts to obtain fishery dependent information, including commercial and recreational catch and effort data for required monitoring and assessment purposes. Increased monitoring of small mesh offshore fisheries suggests that American Shad is encountered as bycatch. Support of improved monitoring of bycatch in marine fisheries where bycatch of shad could occur is necessary to evaluate potential management implications under changing marine and climate-related conditions, which are not well understood.

### **3. ECOLOGICAL**

- 3.1 Evaluate and maximize the ecological contributions for all life-stages of shad on the Connecticut River ecosystem; and

- 3.2 Identify and address impacts to shad habitat for all life stages and life history events, such as river discharge manipulations (e.g., frequency, magnitude, timing, and duration).

### Supporting Narrative

The CRASC's Plan goals and objectives seek to restore the ecological roles of both adults and juvenile shad throughout their historic range in the basin, the estuary, and the marine environment. American Shad serve important ecological roles throughout their complex life history and life stages in these environments (Weiss-Glanz et al. 1986; ASMFC 2009; McDermott et al. 2015) (Table 1).

Table 1. Summary of types of ecological contributions made by shad life stage and location (habitat) with corresponding time periods.

Location	Lifestage	Ecological Services	Timing
Freshwater	Adult (prespawn - post spawn)	Prey item (bald eagle, osprey, larger predatory fishes); marine nutrient transfer	April - July
Freshwater	Early life stage to juvenile	Prey item (fishes and fish eating birds)	July - Nov
Estuarine	Juvenile	Prey item (fishes and fish eating birds)	Aug - Dec
Marine	Juvenile through adult	Prey item (fishes, birds, marine mammals)	Year-round

Barriers in the Connecticut River basin that exclude or restrict adults from accessing spawning habitat can reduce or eliminate the ecological roles of adult and subsequent juvenile life stages (Hall et al. 2012; Freeman et al. 2003). Adult shad also contribute marine derived nutrients to freshwater systems (Hanson et al. 2010). In addition, other hydropower operational concerns, such as peaking flows, outdated minimum flows requirements, diversion of flow (canals or pumped storage reservoir), or partial measure, interim protective measures may also negatively impact achieving ecological contributions. Therefore, achieving many strategies previously stated in this Plan for other Objectives will help meet Objective 3 pertaining to Ecological benefits and need not be repeated as strategies for this Objective.

The ecological benefits of restoring the American Shad run are not fully understood and more research will expand our knowledge. For example, there may be species of mussel that rely on upstream shad migration for dispersal or intricate trophic interactions with shad that are unknown. Understanding these relationships will help CRASC set appropriate objectives for future Plans and educate the public on the value of shad restoration.

## 4. MONITORING AND RESEARCH

- 4.1 Continue enumerating shad at all main stem dams and identified tributaries. Also continue to sample adult shad at the Holyoke Fish Lift to obtain sex specific measures and structures for age and spawning history; and
- 4.2 Continue monitoring juvenile production and explore the need, benefits, options to expand into unmonitored areas; and
- 4.3 Continue monitoring in-river commercial fisheries and explore options for recreational fisheries; and
- 4.4 Work with partners to identify and pursue identified research topics; and
- 4.5 Identify anthropogenic impacts that limit ecological contributions and develop corrective measures.

## Supporting Narrative

American Shad restoration and management requires regular monitoring of fishery dependent and independent metrics to determine population status and trends. Amendment 3 to the ASMFC Interstate Fishery Management Plan for American Shad Management (2010) describes required data for annual state compliance reports as well as data approved for Sustainable Fishery Management Plans. The member agencies of CRASC are responsible for the implementation of current monitoring activities and the means to implement them, as determined appropriate and feasible by each agency. CRASC serves an important coordination role in this regard and may develop new collaborative efforts or mechanisms to develop short-term capacity (e.g., grants). A list of priority annual monitoring information needs and status follow in Table 2.

Table 2. List of priority annual monitoring activities for American Shad in-river.

Activity	Agencies or other	Status
Fishway Counts (main stem and tributaries)	CTDEEP, MADFW, VTDFW, NHFG, Holyoke Gas and Electric, FirstLight Power	Ongoing
Biological sampling, run characterization (size, age, spawning history, by sex)	CTDEEP, from Holyoke Fish Lift	Ongoing
Juvenile Index (lower river)	CTDEEP	Ongoing
Juvenile Index (upper river)	State or federal	Not occurring
Commercial fishery monitoring (catch, effort, by sex, size, age structure)	CTDEEP	Ongoing
Recreational fishery monitoring (catch, effort, by sex, size, age structure)	State or federal	Not occurring

Improved monitoring of recreational fisheries should be considered for a future focal area of management. This type of survey data will aid in providing information on fishing effort, harvest, and biological data to support management decisions and program activities.

The CRASC Technical Committee should continue to assess current information and identify research needs on an annual basis. Determining the number of American Shad that enter the river annually remains a high research priority. Other research priorities include multiple FERC relicensing studies that will provide data on adult and juvenile migration patterns, interaction at dams, fishways, and the Northfield Mountain Pump Storage project (includes larval entrainment study), and passage under varying project operation and river conditions. Study results have started to become available (beginning in 2016) and will provide important information that will require additional review and consideration. The CRASC American Shad Status Report (2015) provides comprehensive details on both research and monitoring needs.

## 5. PUBLIC EDUCATION AND OUTREACH

- 5.1 Provide regular updates on fishway counts in the spring run period on the U.S. Fish and Wildlife Service Connecticut River Fish and Wildlife Conservation Office's (FWCO) web site, seek

opportunities to share information with various media outlets, and promote shad as a natural resource; and

- 5.2 Develop information products for a variety of target audiences that communicates the diverse benefits of a restored shad population as defined by this Plan's goals and objectives.

### **Supporting Narrative**

Providing current information on the status of American Shad and how this Plan is relevant to the public will help create and maintain support for management actions and an appreciation for the species. Public awareness on management and research activities and needs can be achieved from CRASC outreach efforts, including identifying principal contacts in each state and by agency. Interested public may be utilized as Citizen Scientists to assist in agency field sampling activities (for adults or juveniles) and other tasks that may be limited by available seasonal staff. The Connecticut River Fish and Wildlife Conservation Office maintains a web site, <https://www.fws.gov/r5crc/>, that includes: CRASC and ASMFC plans and documents and web links, CRASC meeting minutes, contact information for CRASC announcements, in-season fishway fish counts updates and basin summary fishway counts, and the office's annual report that highlights a wide range of shad management and related activities. The CRASC will support and promote public viewing and educational opportunities at suitable fishways and provide input on messaging at various dams along the Connecticut River.

### **LITERATURE CITED**

- ASMFC (Atlantic States Marine Fisheries Commission). 2014. American Shad Habitat Plan for the State of Connecticut. Washington, D.C. Available at - [http://www.asmfc.org/files/ShadHabitatPlans/AmShadHabitatPlan\\_CT.pdf](http://www.asmfc.org/files/ShadHabitatPlans/AmShadHabitatPlan_CT.pdf)
- ASMFC (Atlantic States Marine Fisheries Commission). 2014. American Shad Habitat Plan for the Connecticut River. Washington, D.C. Available at - [http://www.asmfc.org/files/ShadHabitatPlans/AmShadHabitatPlan\\_CTriver.pdf](http://www.asmfc.org/files/ShadHabitatPlans/AmShadHabitatPlan_CTriver.pdf)
- ASMFC (Atlantic States Marine Fisheries Commission). 2010. Amendment 3 to the Interstate Fishery Management Plan for Shad and River Herring (American Shad Management). Washington, D.C. Available at - [http://www.asmfc.org/uploads/file/Amendment3\\_FINALshad.pdf](http://www.asmfc.org/uploads/file/Amendment3_FINALshad.pdf)
- ASMFC (Atlantic States Marine Fisheries Commission). 2009. Atlantic Coast Diadromous fish habitat: a review of utilization, threats, recommendations, for conservation and research needs. Washington, D.C.. Available at - [http://www.asmfc.org/files/Habitat/HMS9\\_Diadromous\\_Habitat\\_2009.pdf](http://www.asmfc.org/files/Habitat/HMS9_Diadromous_Habitat_2009.pdf)
- ASMFC (Atlantic States Marine Fisheries Commission). 2007. American Shad stock assessment for peer review, Volume 1 and Volume 2. Stock Assessment Report No. 07-01. Washington, D.C. Available at - <http://www.asmfc.org/uploads/file/2007ShadStockAssmtReportVolume1.pdf>
- Castro-Santos, T and B. H. Letcher. 2010. Modeling migratory energetics of Connecticut River American Shad (*Alosa sapidissima*): implications for the conservation of an iteroparous anadromous fish. Canadian Journal of Fisheries and Aquatic Science, 67: 806-830.
- CRASC (Connecticut River Atlantic Salmon Commission). 1992. A Management Plan for American Shad in the Connecticut River Basin. Sunderland, MA. Available at - [http://www.fws.gov/r5crc/pdf/shad\\_management\\_plan.pdf](http://www.fws.gov/r5crc/pdf/shad_management_plan.pdf)
- CRASC (Connecticut River Atlantic Salmon Commission). 2004 (amended). Management Plan for River Herring in the Connecticut River Basin. Sunderland, MA. Available at - [http://www.fws.gov/r5crc/herring\\_plan.html](http://www.fws.gov/r5crc/herring_plan.html)

- CTDEEP (Connecticut Department of Energy and Environmental Protection). 2012. Connecticut River American Shad Sustainable Fishing Plan: Submitted to the ASMFC, September 2012. Marine Fisheries Headquarters, Old Lyme, CT.
- CTDEEP (Connecticut Department of Energy and Environmental Protection). 2010. Report on Future Sustainability of Connecticut River Shad under the Current In-river Commercial and Recreational Fisheries; Report to the ASMFC American Shad Technical Committee. Marine Fisheries Headquarters, Old Lyme, CT.
- Dadswell, M. J., G. D. Melvin, P. J. Williams, and D. E. Themelis. 1987. Influences of origin, life history, and chance on the Atlantic Coast migration of American shad. American Fisheries Society Symposium 1:313-330.
- Freeman, M. C., C. M. Pringle, E. A. Greathouse, and B. J. Freeman. 2003. Ecosystem-level consequences of migratory faunal depletion caused by dams. Pages 255-266 in K. E. Limburg and J. R. Waldman, editors. Biodiversity, status, and conservation of the world's shads. American Fisheries Society, Symposium 35, Bethesda, Maryland.
- Gephard, S. and J. McMenemy. 2004. An overview of the program to restore Atlantic salmon and other diadromous fishes to the Connecticut River with notes on the current status of these species in the river. Pages 287-317 in P. M. Jacobson, D. A. Dixon, W. C. Leggett, B.C. Marcy, Jr., R.R. Massengill, editors. The Connecticut River Ecological Study (1965-1973) revisited: ecology of the lower Connecticut River 1973-2000. American Fisheries Society, Monograph 9, Bethesda, Maryland.
- Hall, C. J., A. Jordan, M. G. Frisk 2012. Centuries of anadromous forage fish loss: Consequences for ecosystem connectivity and productivity. BioScience Vol. 62 No. 8.
- Hendrick, M. L., R. L. Hoopes, D. A. Arnold, and M. L. Kaufmann. 2002. Homing of hatchery-reared American Shad to the Lehigh River, a tributary to the Delaware River. North American Journal of Fisheries Management 22:243-248.
- Hillborn, R., T. P. Quinn, D. E. Schindler, and D. E. Rogers. 2003. Biocomplexity and fisheries sustainability. Proceedings of the National Academy of Sciences 100: 6564-6568.
- Kerr, L.A., S.X. Cadrin, and D.H. Secor. 2010. Simulation modeling as a tool for examining the consequences of spatial structure and connectivity to local and regional population dynamics. ICES Journal of Marine Science 67: 1631-1639.
- Leggett, W. C. 1976. The American shad (*Alosa sapidissima*), with special reference to its migration and population dynamics in the Connecticut River. Page 169-225 in D. Merriman and L. M. Thorpe, editors; The Connecticut River Ecological Study, The Impact of a Nuclear Power Plant. American Fisheries Society, Monograph 1, Bethesda, Maryland.
- Leggett, W. C., and J. E. Carscadden. 1978. Latitudinal variation in reproductive characteristics of American Shad (*Alosa sapidissima*): Evidence for population specific life history strategies in fish. Journal of the Fisheries Research Board of Canada 35: 1469-1478.
- Leggett, W. C., T. F. Savoy, and C. A. Thomichuk. 2004. The impact of enhancement initiatives on the structure and dynamics of the Connecticut River population of American Shad. Pages 391-405 in P. M. Jacobson, D. A. Dixon, W. C. Leggett, B.C. Marcy, Jr., R.R. Massengill, editors. The Connecticut River Ecological Study (1965-1973) revisited: ecology of the lower Connecticut River 1973-2000. American Fisheries Society, Monograph 9, Bethesda, Maryland.
- Limburg, K. E., K. A. Hattala, and A. Kahnle. 2003. American Shad in its native range. Pages 125-140 in K. E. Limburg and J. R. Waldman, editors. Biodiversity, status, and conservation of the world's shads. American Fisheries Society, Symposium 35, Bethesda, Maryland.

- Marcy, B. C. 1976. Early life history studies on American shad in the lower Connecticut River and the effects of the Connecticut Yankee Plant. Page 141-168 in D. Merriman and L. M Thorpe, editors; The Connecticut River Ecological Study, The Impact of a Nuclear Power Plant. American Fisheries Society, Monograph 1, Bethesda, Maryland.
- MADMF (Massachusetts Division of Marine Fisheries). 2012. Massachusetts Sustainable Fishing Plan for American Shad (*Alosa sapidissima*). MADMF, New Bedford, MA.
- McBride, R. S., R. Ferreri, E. K. Towle, J. M. Boucher, and G. Basilone. 2016. Yolke oocyte dynamics support agreement between determinate and indeterminate-method estimates of annual fecundity for a northeastern United States population of American Shad. PLoS ONE 11(10): e0164203.doi
- McDermott, S. P., N. C. Bransome, S. E. Sutton, B. E. Smith, J. S. Link, and T. J. Miller. 2015. Quantifying alosine prey in the diets of marine piscivores in the Gulf of Maine. Journal of Fish Biology 86: 1811-1829.
- MDMR (Maine Department of Marine Resources). 2008. Strategic plan for the restoration of diadromous fishes to the Penobscot River. Maine Department of Marine Resources, Augusta, Maine.
- Normandeau Associates Inc. 2016. TranCanada Hydro, ILP Study 21, American Shad telemetry study report. TransCanada Hydro relicensing study reports: Available at - <http://www.transcanada-relicensing.com/overview/documents/>
- O'Donnell, M. J. and B. H. Letcher. 2008. Size and age distributions of juvenile Connecticut River American Shad above Hadley Falls: Influence on outmigration representation and timing. River Research and Applications 24:929-940.
- O'Leary, J. A. and B. Kynard. 1986. Behavior, length, and sex ratio of seaward migrating juvenile American shad and blueback herring in the Connecticut River. Transactions of the American Fisheries Society Volume 115, Issues 4, pages 529-536.
- Secor, D.H. 2007. The year-class phenomenon and the storage effect in marine fishes. Journal of Sea Research 57: 91-103.
- SRAFRC (Susquehanna River Anadromous Fish Restoration Cooperative). 2010. Migratory fish management and restoration plan for the Susquehanna River basin. U. S. Fish and Wildlife Service, Annapolis, MD.
- Savoy, T. F. and V. A. Crecco. 2004. Factors affecting the recent decline of blueback herring and American Shad in the Connecticut River. Pages 361-377 in P. M. Jacobson, D. A. Dixon, W. C. Leggett, B. C. Marcy, Jr., R.R. Massengill, editors. The Connecticut River Ecological Study (1965-1973) revisited: ecology of the lower Connecticut River 1973-2000. American Fisheries Society, Monograph 9, Bethesda, Maryland.
- Teaming with Wildlife (TWW). 2015. Web site with State Wildlife Conservation Strategies: <http://www.teaming.com/state-wildlife-action-plans-swaps>
- Schindler, D.E., R. Hilborn, B. Chasco, C.P. Boatright, T.P. Quinn, L.A. Rogers, and M.S. Webster. 2010. Population diversity and the portfolio effect in an exploited species. Nature 465: 609-612.
- Walburg, C. H. and P. R. Nichols. 1967. Biology and management of the American Shad and status of the fisheries, Atlantic Coast of the United States, 1960. Special Scientific Report – Fisheries No. 550. U. S. Fish and Wildlife Service, Washington, D.C.

Weiss-Glanz, L. S., J. G. Stanley, and J. R. Moring. 1986. Species profiles; Life histories and environmental requirements of coastal fishes and invertebrates (North Atlantic) – American Shad. U. S. Fish and Wildlife Service Biological Report No. 82 (11.59), and U. S. Army Corps of Engineers report No. TR EL-82-4, Washington, D.C.

## **Appendix A**

A list of legal authorities and select agreements for American Shad management, restoration and related activities (e.g., fish passage) in the Connecticut River basin.

### **Legal Authorities**

- The Fish and Wildlife Coordination Act 1934; as amended
- Federal Power Act 1920; as amended 1935, 1986
- Fish and Wildlife Act 1956
- Federal Aid in Fish Restoration Act 1950 (Dingell-Johnson Act); as amended
- Anadromous Fish Conservation Act 1965
- Clean Water Act 1972
- Connecticut River Atlantic Salmon Compact (Act) 1983
- Silvio Conte National Fish and Wildlife Refuge Act 1991
- State of New Hampshire General Laws, Title XVIII, Chapter 211, Section 211:8
- Commonwealth of Massachusetts, General Laws, Title XIX, Chapter 130,
- Connecticut Gen. Statutes Sec. 26, Chapter 493 and 494
- Connecticut Gen. Statutes Sec. 26-111
- Connecticut Gen. Statutes Sec. 26-115
- Connecticut Gen. Statutes Sec. 26-142(d)

### **Agreements**

- 1967 Statement of Intent for a Cooperative Fishery Restoration Program for the Connecticut River Basin (State and Federal agency Directors; Policy Committee for Fisheries Management of the Connecticut River and Technical Committee)
- 1978 FERC Settlement Agreement(s), Upstream Fish Passage, (formerly New England Power Company and Western New England Power)
- 1990 Memorandum of Agreement(s), CRASC, Connecticut River Downstream Fish Passage, (formerly Northeast Utilities and New England Power Company)

## Appendix B

### Background on American Shad life history and biology.

American Shad is an anadromous fish species with a native range that extends from the St. Lawrence River, Canada, to the St. John's River, Florida with introductions and range expansion along the Northwest Pacific Coast. American Shad is considered in the marine environment to be pelagic and highly migratory, moving between summer feeding areas and overwintering areas (ASMFC 2009). Mature adults home back to natal rivers to spawn in freshwater habitat typically as males at age-4 and age-5 and as females at age-4 and age-5 for first time spawners. A latitudinal variation in the ability to spawn more than once (iteroparity) occurs from Cape Hatteras, North Carolina and northward, with rates in repeat spawners proportions generally increasing in that direction (Limberg et al. 2003). The spawning run typically last 2-3 months, with the Connecticut River stock entering the river between late March and early April, depending on the environmental conditions. River entry is often associated with river temperatures reaching ~10°C (50°F) (Leggett 1976).

American Shad is a broadcast spawner and eggs are initially semi-buoyant, becoming demersal and gradually sinking to the substrate. Connecticut River female fecundity has been determined to average 303,000 eggs with a standard deviation of 75,000 in a recent NOAA Fisheries study that also described the batch timing of egg maturation (McBride et al. 2016). In addition, the same NOAA study reported a mean of 6.7 batches (spawning frequency) for sampled females that averaged 45,950 eggs. Spawning activity is primarily nocturnal and has been documented occurring in shoal areas and in defined areas such as Windsor Locks (rkm 78), Wilson (rkm 74) and Rocky Hill (rkm 51)(Marcy 1976), but also has been noted as being more widely occurring among habitat types (ASMFC 2009). Other in-river spawning studies have been conducted between the Holyoke Dam and Turners Falls Dam, Massachusetts by the University of Massachusetts Amherst Cooperative Research Unit during the 1970s and 1980s. Recent relicensing study for the Turners Falls Dam/Project, including areas upstream to Vernon Dam, as well as from Vernon Dam to Bellows Falls Dam have been surveyed for spawning activity. American Shad spawn repeatedly, typically occurring in water temperatures ranging from 15 – 23°C, with eggs developing over time in relation to water temperature (ASMFC 2009). Egg development occurs in relation to water temperatures, with hatching in 14 - 20°C water taking approximately 3 days (Marcy 1976). Yolk sac larvae transition to first feeding larvae after a period of 4 - 7 days (water temperature dependent) at a size of 10 - 12mm (ASMFC 2009).

Juvenile shad may use a variety of habitats as they grow and feed on zooplankton and are also opportunistic users of other prey items (ASMFC 2009). The growth rate of juvenile shad has been shown to be consistently faster in upstream areas compared with downstream areas in the Connecticut River main stem and in comparison to the Farmington River (Marcy 1976). Juvenile outmigration has been reported to occur after a period of 80 days, which corresponded to a length of approximately 75mm (O'Donnell and Letcher). Decreasing water temperature has also been correlated with the peak juvenile outmigration, at the Holyoke Dam, initiating at 19°C and peaking from 14 - 9°C, and ending at 10 - 8°C in the study period (O'Leary and Kynard 1986). Information on American Shad in the marine environment is inherently more limited. Three main offshore overwintering areas have been described consisting of; 1) off of the Scotian Shelf/Bay of Fundy, 2) Middle Atlantic Bight, and 3) off the Florida Coast (Dadswell et al. 1987). Summer feeding areas contain mixed stocks that aggregate in the upper Bay of Fundy and Gulf of Maine, the St. Lawrence estuary, and off of Newfoundland and Labrador (Dadswell et al. 1987).

### Appendix C

Estimated number of American Shad entering the Connecticut River from CTDEEP 2010, and CTDEEP Annual Compliance Report to ASMFC (2016).

Year	Estimate	Year	Estimate
1966	695,000	1991	1,196,000
1967	637,000	1992	1,628,000
1968	410,000	1993	749,000
1969	591,000	1994	326,000
1970	488,000	1995	304,000
1971	583,000	1996	667,000
1972	485,000	1997	659,000
1973	613,000	1998	651,000
1974	372,000	1999	475,000
1975	598,000	2000	427,000
1976	740,000	2001	773,000
1977	323,000	2002	687,000
1978	710,670	2003	527,000
1979	632,820	2004	351,000
1980	759,420	2005	226,000
1981	909,270	2006	294,667
1982	939,330	2007	243,755
1983	1,574,000	2008	276,864
1984	1,231,000	2009	321,338
1985	728,000	2010	279,000
1986	748,000	2011	387,000
1987	588,000	2012	778,462
1988	648,000	2013	623,757
1989	979,000	2014	588,105
1990	816,000	2015	687,760

## Appendix D

Existing fishways for American Shad in the Connecticut River basin.

<i>Main stem (rkm)</i>	<b>Project/Dam</b>	<b>Upstream Fishway Design</b>	<b>Status</b>
139	Holyoke	Fish lift	Lifts new in 2004 and 2015 modifications driven by downstream passage requirements, evaluation studies planned for 2016
198	Turners Falls	Modified Ice Harbor and vertical slot	Long standing passage issues, study and modifications; Cabot Station Ladder, Spillway Ladder and Gatehouse Ladder (vertical slot), evaluation studies in 2015 (FERC relicensing)
228	Vernon	Modified Ice Harbor and vertical slot	Evaluation studies in 2015 (FERC relicensing)
280	Bellows Falls	Vertical slot	Historic upstream extent of distribution, with ladder in place, upstream passage is possible
<i>Tributary (name)</i>			
Mattabesset River	StanChem	Denil	First year operation 2013, not evaluated
Farmington River	Rainbow	Vertical slot	Long standing issues with shad passage, CTDEEP owned facility, new fish lift design pending, not evaluated
Westfield River	West Springfield	Denil	Not evaluated
Manhan River	Manhan	Denil	First year of operation 2014, not evaluated
Ashuelot River	Fiske Mill	Fish lift	Not evaluated, known issues with false attraction to tailwater

## Appendix E

Annual counts of American Shad recorded at upstream passage fishways on the main stem dams and select tributaries. No shad have been reported lifted at the Fisk Mill Dam, Ashuelot River, NH or passing the Manhan River, Easthampton, MA.

Year	Holyoke Dam Passed	Turners Falls Dam Passed	Vernon Dam Passed	Bellows Falls Dam Passed	Farmington River, Rainbow Dam Passed	Westfield River, W. Springfield Dam Passed
1955	4,900					
1956	7,700					
1957	8,800					
1958	5,700					
1959	15,000					
1960	15,000					
1961	23,000					
1962	21,000					
1963	31,000					
1964	35,000					
1965	34,000					
1966	16,000					
1967	19,000					
1968	25,000					
1969	45,000					
1970	66,000					
1971	53,000					
1972	26,000					
1973	25,000					
1974	53,000					
1975	111,000					
1976 <sup>A</sup>	346,725				<b>1,189</b>	
1977	202,997				804	
1978	145,136				1,053	
1979	255,753				514	
1980	376,066	<b>298</b>			480	
1981	377,124	200	<b>97</b>		167	
1982	294,842	11	9		737	
1983	528,185	12,705	2,597		1,565	
1984	496,884	4,333	335	<b>1</b>	2,289	
1985	487,158	3,855	833	0	1,042	
1986	352,122	17,858	982	0	1,206	
1987	276,835	18,959	3,459	39	792	
1988	294,158	15,787	1,370	24	378	
1989	354,180	9,511	2,953	*	215	
1990	363,725	27,908	10,894	0	432	
1991	523,153	54,656	37,197	65	591	
1992	721,764	60,089	31,155	103	793	
1993	340,431	10,221	3,652	2	460	

Year	Holyoke Dam Passed	Turners Falls Dam Passed	Vernon Dam Passed	Bellows Falls Dam Passed	Farmington River, Rainbow Dam Passed	Westfield River, W. Springfield Dam Passed
1994	181,038	3,729	2,681	3	250	
1995	190,295	18,369	15,771	147	246	
1996	276,289	16,192	18,844	1	668	<b>1,413</b>
1997	299,448	9,216	7,384	46	421	1,012
1998	315,810	10,527	7,289	55	262	2,292
1999	193,780	6,751	5,097	110	70	2,668
2000	225,042	2,590	1,548	9	283	3,558
2001	273,206	1,540	1,744	**	153	4,720
2002	374,534	2,870	356	**	110	2,762
2003	286,814	--	268	*	76	1,957
2004	191,555	2,192	653	**	123	913
2005	116,511	1,581	167	3	8	1,237
2006	154,745	1,810	133	0	73	1,534
2007	158,807	2,248	65	0	156	4,497
2008	153,109	4,000	271	0	89	3,212
2009	160,649	3,813	16	0	35	1,395
2010	164,439	16,422	290	0	548	3,449
2011	244,177	16,798	46	1	267	5,029
2012	490,431	26,727	10,386	0	174	10,300
2013	392,967	35,293	18,220	0	84	4,900
2014	370,506	39,914	27,706	0	536	4,787
2015	412,656	58,079	39,771	44	316	3,383
2016	385,930	54,069	35,732	1,973 <sup>B</sup>	141	5,940
Mean	310,975 <sup>A</sup>	15,864	8,055	-	483	3,379
standard deviation	130,295	17,691	11,951	-	472	2,193
minimum	116,511	11	9	-	8	913
maximum	721,764	60,089	39,771	-	2,289	10,300

<sup>A</sup> Holyoke shad passage summary statistics only for the period 1976-2016

\* Ladder not operated

\*\* No fish count monitoring

<sup>B</sup> Bellows Falls is the historic upstream extent of the species range. The Bellows Falls Project fish ladder was, by agreement, operationally triggered on Atlantic Salmon upstream passage needs, so its period of operation was often limited/restricted in the past. In many years no shad were observed passing at this facility. Beginning in 2013, TransCanada agreed to open this ladder based on a trigger of 100 Sea Lamprey passed at Vernon Dam providing an opportunity for upstream habitat access.

## Appendix F

Connecticut Department of Energy and Environmental Protection, Marine Fisheries Division, Juvenile Alosine Seine Survey data for the period 1978-2015. The reported index value is a geometric mean catch of juvenile American Shad from all stations and all dates, annually. Seven sites from Holyoke, MA, to Essex, CT are sampled weekly from mid-July through mid-October.

Year	Index	Year	Index
1978	5.9	1997	6.8
1979	7.8	1998	3.7
1980	9.2	1999	5.5
1981	6.1	2000	4.4
1982	1.8	2001	2.7
1983	5.0	2002	5.6
1984	3.4	2003	6.9
1985	7.1	2004	5.6
1986	6.3	2005	10.1
1987	9.9	2006	1.8
1988	5.7	2007	8.2
1989	4.9	2008	5.1
1990	10.4	2009	3.4
1991	3.9	2010	10.2
1992	7.2	2011	3.1
1993	9.5	2012	3.0
1994	12.2	2013	3.2
1995	1.3	2014	8.0
1996	6.5	2015	8.5

## Appendix G

Connecticut Department of Energy and Environmental Protection, Marine Fisheries Division, proportion of adult American Shad repeat spawners from sample sources transitioning from lower river gillnet (1960s) to primarily Holyoke Fish Lift (1990s-2000s). Data from CTDEEP 2010 and from subsequent annual Compliance reports to the Atlantic States Marine Fisheries Commission.

Year	Repeat	Year	Repeat
1966	0.53	1991	0.15
1967	0.53	1992	0.08
1968	0.34	1993	0.16
1969	0.38	1994	0.39
1970	0.39	1995	0.20
1971	0.45	1996	0.14
1972	0.41	1997	0.12
1973	0.44	1998	0.15
1974	0.22	1999	0.08
1975	0.24	2000	0.15
1976	0.26	2001	0.21
1977	0.10	2002	0.22
1978	0.24	2003	0.05
1979	0.18	2004	0.11
1980	0.19	2005	0.11
1981	0.11	2006	0.02
1982	0.15	2007	0.07
1983	0.20	2008	0.02
1984	0.27	2009	0.05
1985	0.23	2010	0.07
1986	0.21	2011	0.09
1987	0.44	2012	0.04
1988	0.15	2013	0.10
1989	0.21	2014	0.03
1990	0.17	2015	0.02

## Appendix H

Annual commercial landings (in kilograms) of American Shad for Connecticut (NOAA Commercial statistics).

Year	kg	Year	kg	Year	kg
1887	152,861	1930	24,494	1973	116,845
1888	127,913	1931	34,019	1974	112,128
1889	88,904	1932	31,751	1975	75,070
1890	54,431	1933	60,328	1976	177,808
1891	35,380	1934	238,136	1977	150,774
1892	28,576	1935	182,798	1978	138,935
1893	64,864	1936	174,633	1979	93,803
1894	114,305	1937	173,726	1980	140,840
1895	98,883	1938	193,684	1981	147,281
1896	118,388	1939	185,519	1982	128,367
1897	116,120	1940	163,293	1983	193,230
1898	226,343	1941	198,673	1984	180,963
1899	150,139	1942	169,190	1985	182,344
1900	222,260	1943	250,837	1986	146,488
1901	196,859	1944	338,833	1987	151,454
1902	217,724	1945	349,992	1988	85,956
1903	279,413	1946	519,862	1989	82,679
1904	273,516	1947	359,563	1990	119,066
1905	219,992	1948	281,953	1991	68,166
1906	114,759	1949	213,506	1992	65,614
1907	61,689	1950	119,522	1993	43,954
1908	55,338	1951	153,314	1994	48,022
1909	55,338	1952	215,048	1995	27,958
1910	44,452	1953	163,021	1996	66,299
1911	43,545	1954	133,991	1997	85,121
1912	95,254	1955	95,345	1998	82,663
1913	83,461	1956	89,222	1999	65,426
1914	92,079	1957	149,050	2000	98,532
1915	67,132	1958	206,974	2001	26,868
1916	83,461	1959	181,800	2002	49,033
1917	102,512	1960	181,392	2003	50,406
1918	109,316	1961	210,195	2004	30,081
1919	210,013	1962	206,747	2005	31,444
1920	79,832	1963	136,441	2006	17,482
1921	32,659	1964	125,963	2007	23,389
1922	21,319	1965	159,755	2008	12,888
1923	20,865	1966	109,724	2009	12,611
1924	40,370	1967	108,862	2010	11,187
1925	66,224	1968	96,343	2011	12,133
1926	50,349	1969	86,137	2012	19,712
1927	54,431	1970	78,517	2013	18,453
1928	90,265	1971	109,180	2014	15,473
1929	144,242	1972	113,035	2015	23,135

## Appendix I

### Summary of estimated habitat

Table A. The estimated spawning and rearing habitat for American Shad by river segment in relation to estimated adult shad production/return potential, and minimum target fish passage numbers by barrier.

Reach	m <sup>2</sup>	Ha	Adjustment	Ha	% of total	Adult Shad Return/Production (203 and 111 settings by habitat)	Project	Minimum target number
Main stem - mouth to Holyoke	56,766,060	5,677	0.85	4,825	54.8	979,498		
tributaries (5)		424		424	4.8	47,064		
Main stem - Holyoke to Turners Falls	13,688,717	1,369		1,369	15.5	277,881	Holyoke Fish Lift - passage	687,088
tributaries (2)		109		109	1.2	12,099		
Main stem - Turners to Vernon	7,620,241	762		762	8.7	154,691	Turners Falls Project - passage	397,108
tributaries* (1)		139		139	1.6	15,429		
Main stem - Vernon to Bellows Falls	10,421,641	1,042		1,042	11.8	211,559	Vernon Ladder - passage	226,988
tributary (1)		139		139	1.6	15,429		
<b>Totals</b>		<b>9,661</b>		<b>8,809</b>	<b>100.00</b>	<b>1,713,651</b>		

\*Millers River habitat area undefined

Table B. The estimated spawning and rearing habitat for American Shad, by tributary in relation to estimated adult shad production/return potential.

Tributary	Total rkm	Area (est) ha	Adult Shad Return/Production
Mattabesset, CT	36.3	54.5	6,044
Farmington, CT	60.3	211.1	23,427
Pequabuck, CT	12.4	9.9	1,101
Scantic, CT	22.4	31.4	3,481
Westfield, MA	29.4	117.6	13,054
Chicopee, MA <sup>A</sup>		T.B.D.	
Manhan, MA	23.0	23.0	2,553
Deerfield, MA	21.5	86.0	9,546
Millers, MA <sup>B</sup>		T.B.D.	
Ashuelot, NH	60.0	139.0	15,429
West, VT	31.0	139.5	15,485
			90,119
<sup>A</sup> - First dam is ~ 1 rkm from confluence with numerous subsequent dams			
<sup>B</sup> - Relatively high gradient tributary, more data required			